Antenna Axis Drive Torques for the 70-Meter Antenna

H. McGinness
Ground Antennas and Facilities Engineering Section

Antenna axis speeds versus wind speeds are given in terms of dish size, hydraulic-motor size, and the number of servo valves.

I. Introduction

An increase in the dish diameter of an antenna is usually accompanied by increases in the axis torques required to drive the antenna against wind. The proposed increase in the diameters of the 64-m antenna dishes to 70 m (plus a noise shield) does require increased axis torques. This report shows the effect of these increased torques on the axis speeds.

II. Description of the Axis Drives

The azimuth-axis drive is composed of a large bull gear, four speed reducers, each of which is driven by two hydraulic motors, a brake, a servo valve, and the necessary hydraulic power source.

The elevation-axis drive is similar, but has two bull gears in parallel, each of which is driven by two speed-reducer units. One hydraulic motor on the input end of each speed reducer applies a constant torque which is equilibrated by an equal and opposite torque from a hydraulic motor on one of the other speed reducers. These countertorquing motors serve to keep the drive system free of backlash. Each speed reducer also has a second motor attached to its input end, and these motors are termed the torquing motors. The torquing motors of each axis drive are controlled by a single servo valve. Figure 1 is a schematic of two drive units and a bull gear. In actuality the motors connect to the output pinion through a multistage gear reduction. Figure 1 demonstrates that the countertorquing hydraulic system is independent of the torquing hydraulic system, and that only the torquing motors resist wind or inertia torques.

III. Drive Torque Analysis

The maximum torques, induced by wind, about the azimuth and elevation axes are taken from Table VI of Ref. 1, and are as follows, where T_A is the maximum azimuth torque and T_E is the maximum elevation torque (the subscripts 64 and 72 pertain to the 64-m and 70-m antennas, respectively):

$$T_{A64} = 0.117\, q \frac{\pi}{4} D^3 \tag{1}$$

$$T_{A72} = 0.122\, q \frac{\pi}{4} D^3 \tag{2}$$

$$T_{E64} = 0.122\, q \frac{\pi}{4} D^3 \tag{3}$$

$$T_{E72} = 0.123\, q \frac{\pi}{4} D^3 \tag{4}$$

where

q = $1/2\, \rho V^2$ = the dynamic pressure of the wind

ρ = the air density

V = the wind speed

D = the antenna dish diameter

The ratios between the maximum torques of the two antennas may be obtained directly from Eqs. (1), (2), (3), and (4), and are

$$\frac{T_{A72}}{T_{A64}} = \frac{0.122}{0.117}\left(\frac{72}{64}\right)^3 = 1.476 \tag{5}$$

$$\frac{T_{E72}}{T_{E64}} = \frac{0.123}{0.122}\left(\frac{72}{64}\right)^3 = 1.432 \tag{6}$$

The maximum azimuth torque occurs at an elevation angle of 5° and a wind azimuth angle of 120°. The maximum elevation torque occurs at an elevation angle of 60° and a wind azimuth of 180°.

The torque of either antenna axis may be written

$$T_{ANT} = C q \frac{\pi}{4} D^3 = C \frac{1}{2} \rho V^2 \frac{\pi}{4} D^3 = C \frac{\pi}{8} \rho V^2 D^3 \tag{7}$$

where C is the pertinent numerical coefficient appearing in Eqs. (1), (2), (3), and (4).

The pressure drop ΔP across the servo valve, see Fig. 1, is obtained from Ref. 2 and is

$$\Delta P = \left[1 - \left(\frac{Q_L}{Q_{NL}}\right)^2\right] \frac{P_S}{1.15} \tag{8}$$

where

P_S = the supply pressure to the servo valve

Q_L = the load flow through the valve

Q_{NL} = the no-load flow through the valve and is a function of the supply pressure, P_S

The factor, 1.15, allows for line and motor losses.

The load flow, Q_L, can be expressed in terms of the antenna-axis angular speed, since the angular speed is proportional to the flow through the hydraulic motors.

$$Q_L = \frac{\alpha r n d}{360} \text{ volume per unit time} \tag{9}$$

where

α = the axis speed in degrees per unit time

r = the speed ratio between the hydraulic motor and antenna axis

n = the number of motors supplied by one servo valve

d = the motor displacement per turn

Substitute Eq. (9) into Eq. (8) and obtain

$$\Delta P = \left[1 - \left(\frac{\alpha r n d}{360\, Q_{NL}}\right)^2\right] \frac{P_S}{1.15} \tag{10}$$

The output torque from one hydraulic motor, T_{HM}, is

$$T_{HM} = \frac{\Delta P d}{2\pi} \tag{11}$$

Since there are four torquing motors per antenna axis, the motor torque also must be

$$T_{HM} = \frac{T_{ANT}}{4 r \eta} \tag{12}$$

where η is the efficiency of the speed reducer. Equate Eq. (11) to Eq. (12) and obtain

$$\frac{\Delta P d}{2\pi} = \frac{T_{ANT}}{4 r \eta} \tag{13}$$

Substitute Eqs. (10) and (7) into Eq. (13) and obtain

$$\left[1 - \left(\frac{\alpha r n d}{360\, Q_{NL}}\right)^2\right] \frac{P_S}{1.15} \frac{d}{2\pi} = \frac{C \pi \rho V^2 D^3}{32\, r \eta} \tag{14}$$

Solve Eq. (14) for α and obtain

$$\alpha = \frac{360\, Q_{NL}}{r n d} \left[1 - \frac{C \pi^2\, 1.15\, \rho V^2 D^3}{16\, r \eta\, d P_S}\right]^{1/2} \tag{15}$$

For a particular servo valve, the no-load flow, Q_{NL}, is a certain function of the valve-supply pressure, P_S. From Fig. 1 of Ref. 4, which pertains to the servo valve now used on the 64-m antennas (namely MOOG 72-163), the value of Q_{NL} is given graphically as a function of P_S. The displacement per turn of this motor is .0000395 m^3 (2.41 $in.^3$) and the Q_{NL} value is .00580 m^3/s (354 $in.^3/s$) for P_S = 2069 10^4 N/m^2 (3000 psi); the Q_{NL} is .00567 m^3/s (346 $in.^3/s$) for P_S = 1724 10^4 N/m^2 (2500 psi).

From Fig. 133 of Ref. 2 the efficiency of the speed reducer, η, is given as .90 for high torques. From Table 5 of Ref. 2, the speed ratio between motor and antenna axis, r, is 28724 for the azimuth axis and 28730 for the elevation axis. Of the three 64-m antennas, the one at DSS-43 is the closest to sea level, namely 670 m. At this elevation the air density is approximately 96% of the standard sea-level air density. Substituting the foregoing parametric values into Eq. (15), together with the appropriate C values from Eqs. (1), (2), (3), and (4), the curves of Figs. 2 and 3 have been drawn. These curves show the maximum antenna-axis speeds plotted against the wind speed for the antenna attitudes which produce the maximum axis torques.

The error band shown for one of the curves of both Figs. 2 and 3 is based upon a wind moment coefficient error of ± 15%.

The elevation axis torque caused by bearing friction is less than 1% of that coming from a 18 m/s (40 mph) wind. The elevation axis imbalance tends to aid the drive to the stow position; however, it is also of negligible significance.

The azimuth axis torque caused by the hydrostatic bearing and by the cable wrap is less than 1% of that coming from a 18 m/s (40 mph) wind.

IV. Conclusions

The increased dish diameter causes the maximum azimuth and elevation torques to increase 48% and 43%, respectively.

In Fig. 2 the maximum elevation axis speeds are plotted against the wind speed for various values of the parameters appearing in Eq. (13). For the case of the 70-m antenna with a noise shield, abbreviated 72 m, using the same hydraulic drive equipment as now used with the 64-m antenna, but having the hydraulic supply pressure increased, the curve is given with an error band shown cross-hatched. The left edge of the error band intersects the 0.25/s axis speed at a wind speed value of 18.33 m/s (41 mph). This means that at the critical antenna attitude, an elevation axis speed of 0.25/s might be limited to wind speeds less than 18.33 m/s. The left boundary of the error band also shows that at the critical antenna attitude, no elevation drive would be possible at winds greater than 21.7 m/s (48.5 mph). Although the substitution of larger hydraulic motors would extend the driving range at low speeds, the driving range at greater speeds would be reduced. Only by combining an additional servo valve with larger motors can the driving range be increased for all speeds.

In Fig. 3 the maximum azimuth-axis speeds are plotted against the wind speed for various values of the parameters of Eq. (13). The results are similar to those pertaining to the elevation axis.

References

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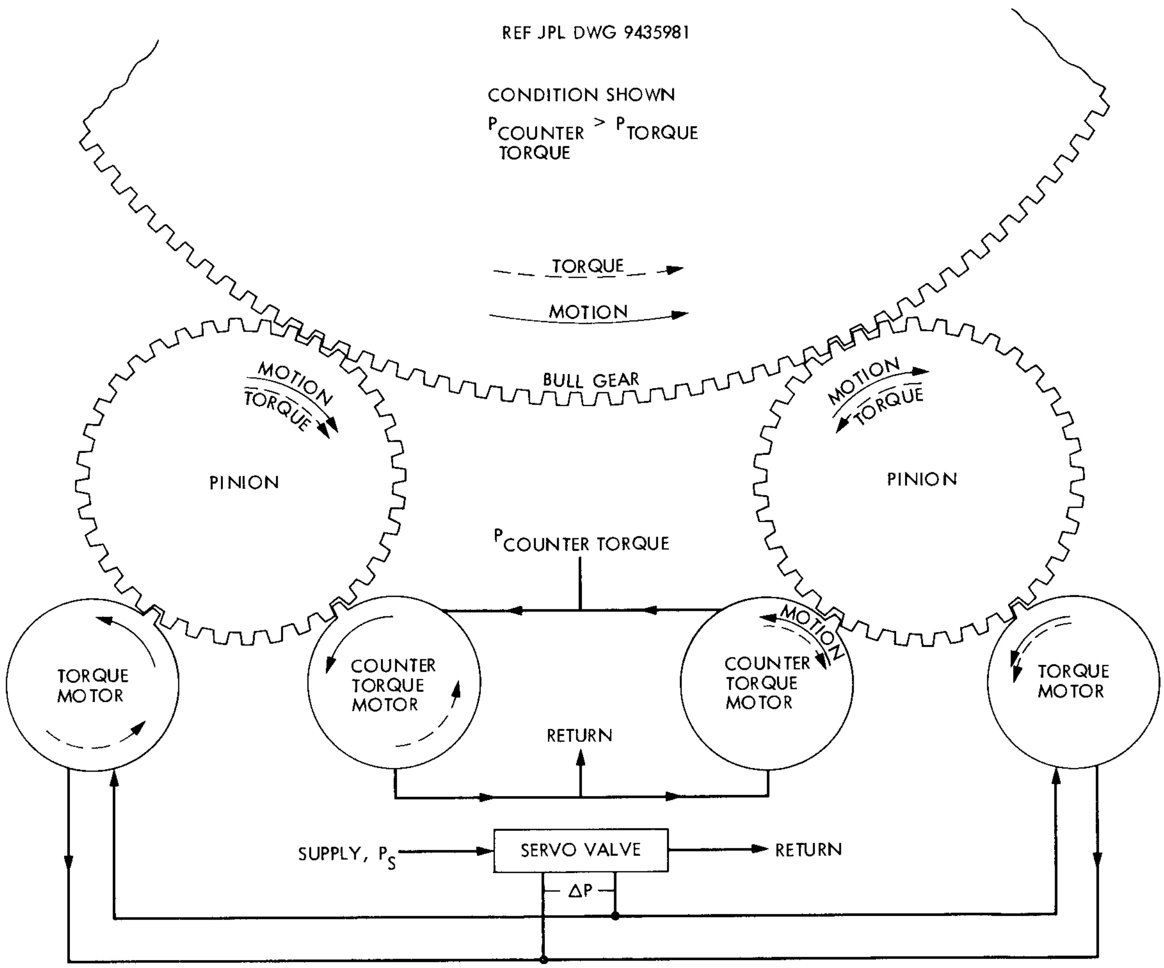

Fig. 1. Schematic of bull gear, pinion, hydraulic motors, and servo valve

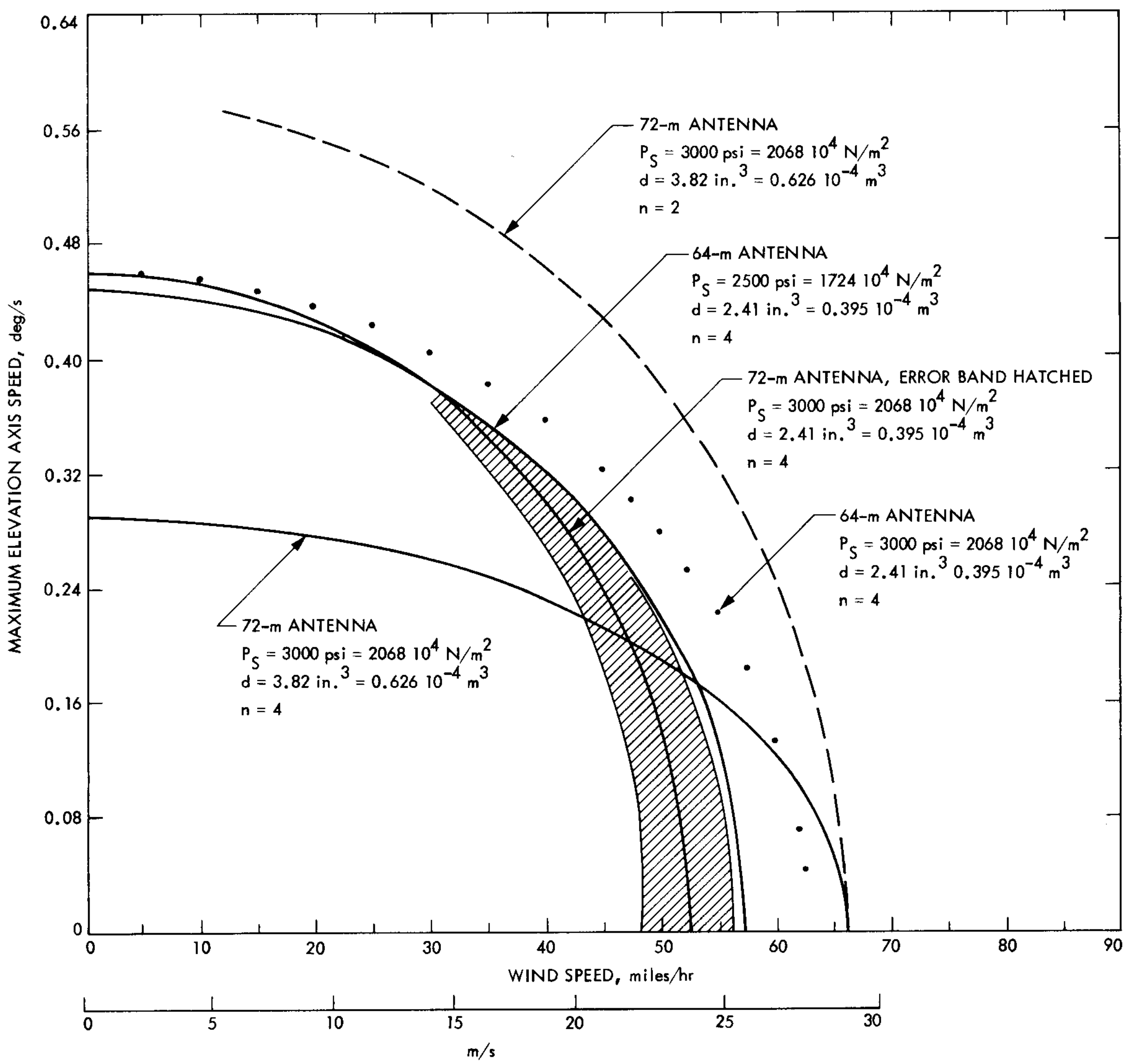

Fig. 2. Maximum elevation axis speed versus wind speed at critical configuration (elevation = 60°, azimuth = 180°, air density = 96% of standard sea-level density)

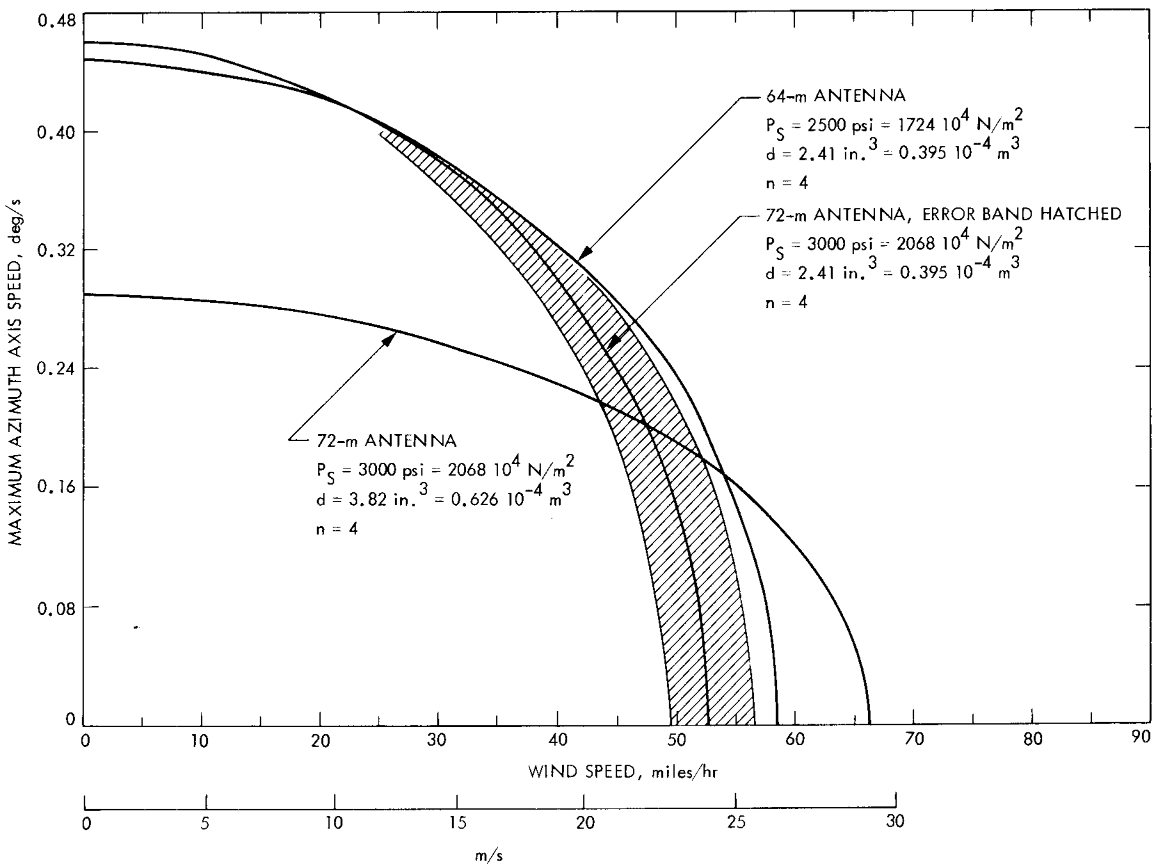

Fig. 3. Maximum azimuth axis speed versus wind speed at critical configuration (elevation = 5°, azimuth = 120°, air density = 96% of standard sea-level density)